The three-body structure of the X(2175) and the Y(4260) states

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Abstract. In this talk, I discuss our study of three-meson systems where we find dynamical generation of two resonances: the X(2175) and the Y(4260). Experimentally, the former one has been found in the mass spectrum of the φf_0(980) system and the latter one in that of the J/ψφπ system. Our study of these systems, using the Faddeev equations, reveals that these resonances possess a three-body structure.

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INTRODUCTION

Recent findings of several meson resonances which do not fit in to the regular quark-antiquark spectrum, named as X, Y, Z resonances (see [1, 2], for example), require looking for alternative understanding of the experimental data. For example, the X(2175) J^−− resonance, seen in the data from BABAR [3, 4] of the e^+e^− → φf_0(980) process studied with initial state radiation (also confirmed at BES in J/ψ → φf_0(980) [5]), has lead to different theoretical studies trying to explain its non-trivial nature in terms of a tetra-quark state or a hybrid state [6]. In [4] this resonance is seen as an enhancement in the K^+K^−K^+K^− cross section around 2150 MeV. A detailed theoretical study of the e^+e^− → φf_0(980) reaction was done in [7] by means of loop diagrams involving kaons and K^∗, using chiral amplitudes for the K^0K → ππ channel which contains the f_0(980) pole generated dynamically by the theory. The study revealed that the loop mechanisms reproduced the background but failed to produce the peak around 2175 MeV, thus reinforcing the claims for a new resonance around this mass. Since in the chiral models the f_0(980) gets dynamically generated in the ππ and K^0K systems, there is a possibility that the X(2175) could be understood as a resonant state of φK^0K^0. We thus investigate the three-body systems φππ and φK^0K^0 considering the interaction of the three particles among themselves. For that we solve the Faddeev equations in the coupled channel approach. We find [8] that the X(2175) gets dynamically generated in the φππ and φK^0K^0 system when the invariant mass of the ππ and K^0K system is close to the f_0(980) region, therefore, indicating, that the X(2175) has a strong coupling to the φf_0(980) system, as experimentally observed.

We have also studied the J/ψKK and J/ψππ systems with the same formalism [9] to look for the Y(4260) resonance. The results of this study show that this resonance has many similarities with the X(2175) and corresponds to a state of J/ψKK with KK clustering as the f_0(980).

FORMALISM

In order to determine the three-body T matrix for the different systems investigated and search for possible states which couple strongly to three-body channels, we follow the formalism developed in [10, 11, 12, 13] which is based on the Faddeev equations. In terms of the Faddeev partitions, T^1, T^2 and T^3, the three-body T-matrix is written as

\[ T = T^1 + T^2 + T^3. \]  
(1)

In our formalism we rewrite these partitions as [10, 11]

\[ T^i = i\phi^3(\vec{k}_i^j - \vec{k}_i^k) + \sum_{j,k=1}^{3} T_{ij}^k, \quad i = 1, 2, 3 \]  
(2)
In Eq. (3), $g_{ij}$ to the three-body $T$-matrix in which the last two interactions are given in terms of the two-body $t$-matrices $t^i$ and $t^j$, respectively and satisfy the equations:

$$
T_R^{12} = t^1 g^{12} t^2 + t^1 \left[ G^{121} T_R^{21} + G^{123} T_R^{23} \right] \\
T_R^{13} = t^1 g^{13} t^3 + t^1 \left[ G^{131} T_R^{31} + G^{132} T_R^{32} \right] \\
T_R^{21} = t^2 g^{21} t^1 + t^2 \left[ G^{212} T_R^{12} + G^{213} T_R^{13} \right] \\
T_R^{23} = t^2 g^{23} t^3 + t^2 \left[ G^{231} T_R^{31} + G^{232} T_R^{32} \right] \\
T_R^{31} = t^3 g^{31} t^1 + t^3 \left[ G^{312} T_R^{12} + G^{313} T_R^{13} \right] \\
T_R^{32} = t^3 g^{32} t^2 + t^3 \left[ G^{321} T_R^{21} + G^{323} T_R^{23} \right].
$$

This means that the full three-body $T$-matrix can be related to $T_R^{ij}$ through:

$$
T = \sum_{i=1}^{3} T^i = \sum_{i=1}^{3} t^i \delta^{ij} (\vec{k}'_i - \vec{k}_i) + T_R
$$

$$
T_R = \sum_{i=1}^{3} \sum_{j\neq i}^{3} T_R^{ij}
$$

In Eq. (3), $g_{ij}$'s correspond to the three-body Green’s function of the system and $G^{ijk}$ to a loop function of three-particles (for their definitions see [10, 11, 12, 13]). We always work with $S$ wave interactions, therefore, all the matrices in Eq. (3) are projected in $S$-wave, thus giving total $J^P = 1/2^+$. In order to identify possible three-body states, we project the $T_R$-matrix (Eq. (4)) on the isospin base. We choose the base in which the states are defined in terms of the total isospin of the three body system, $I$, and the total isospin of two pseudoscalars, $I_{PP}$, i.e., $|I, I_{PP}\rangle$ [11]. Since neither $\sum_{i=1}^{3} t^i \delta^{ij} (\vec{k}'_i - \vec{k}_i)$ nor $t^i g^{ij} t^j$ can give any three-body resonance structure because there are no three-body loops involved in such terms, we study the properties of:

$$
T_R = T_R - \sum_{i=1}^{3} \sum_{j\neq i}^{3} t^i g^{ij} t^j
$$

**RESULTS**

In case of mesons, several new resonances are being found at BES, BELLE, BABAR, CLEO etc., facilities. These resonances do not seem to fit into the known quarkonium spectra and coincidently several of them seem to appear in reactions with three mesons in the final state where two out of the three form a known resonance. In other words, a new resonance seems to develop in a system made of a meson and a meson resonance. Some of examples of such cases are:

- $X(2175)$ found in the $e^+e^- \rightarrow \phi f_0$ reaction by the BABAR and BES collaborations [14].
- $Y(4260)$ found in the $e^+e^- \rightarrow J\psi f_0$ reaction, with exceptionally strong coupling to the $J\psi f_0$ channel, by the BABAR, BES and CLEO collaborations [15].
- $Y(4660)$ found in the $J\psi (2s) f_0$ system by the BELLE collaboration [16].
- $X(1576)$ in the $K^+ K\pi$ system by the BES collaboration. [17], etc.

As mentioned in the introduction, a resonance with mass 2175 MeV has been found in different experimental studies [14] which seems to couple strongly to the $\phi f_0(980)$ system. In [7] the $e^+e^- \rightarrow \phi f_0(980)$ reaction, for which the data are available from BABAR [14], was studied using a loop mechanism involving pseudoscalar and vector meson loops.
In the chiral models, the $f_0(980)$ resonance is dynamically generated in the $K\bar{K}$ interaction [18]. Therefore, a study of the $\phi K\bar{K}$ system could explain the experimental results. In [8] we solved the Eq.(3) taking $\phi K\bar{K}$ and $\phi \pi \pi$ as coupled channels and found a peak in the $\phi K\bar{K}$ channel around 2150 MeV with a width of 20 MeV when the invariant mass of the $K\bar{K}$ system is close to 980 MeV (see Fig. 1), thus, confirming the experimental findings. Using the results of [7], we implemented the final state interaction for the $e^+ e^- \rightarrow \phi f_0(980)$ reaction in terms of our three-body amplitude and calculated the cross sections. This resulted into a peak in the cross section around 2175 MeV in accordance with the experimental cross sections obtained by different experimental groups [14]. Similar findings have also been reported in [19, 20].

We have also studied the $J/\psi K\bar{K}$ and $J/\psi \pi \pi$ systems in order to look for the $Y(4260)$ resonance, which as mentioned in [9] seems to be very similar to the $X(2175)$ resonance and where we report the finding of a resonance which can be related to the $Y(4260)$. As it can be seen in Fig. 2, the resonance appears when the invariant mass for the $K\bar{K}$ pair is close to 980 MeV, which means that the $Y(4260)$ has an important $J/\psi f_0(980)$ component.
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